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Article

Evaluation of Tomato Landraces for Tolerance to Drought Stress Using Morphological and Physiological Traits

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Abstract: Drought is among the stress factors that, on a global scale, have direct negative effects on plant growth, yield, and quality. Great efforts are directed towards water shortage adaptation. Exploring the genetic diversity of landraces often tolerant to locally occurring stress can represent a valuable source for the development of cultivars with yield stability and improved quality under stress conditions. This study aimed to identify drought-tolerant tomato landraces based on an integrated approach involving morphological traits and physiological parameters. To investigate the effects of water deficit, five landraces and two controls were tested under optimum and 50% reduced irrigation. Yield and yield-related traits, color, firmness, and chlorophyll fluorescence measurements were evaluated. The summarized results indicated that the tomato landraces differed in their responses to water deficit. Water deficit decreased the yield by 44% and the average fruit weight by 29%. Physiological parameters were also significantly affected by water scarcity, with a decrease in the ratios Fv/Fm (the maximum quantum yield of PSII) and Fv/Fo (the maximum primary yield of photochemistry) of 8.2% and 35.5%, respectively, at 14 days' exposure to stress. Landrace 1352, characterized by indeterminate growth habit and large, rounded, and red-colored fruits, showed a significantly lower reduction in yield and physiological parameters under reduced irrigation and could be used in breeding programs to develop new tomato lines combining resistance with quality.

Keywords: *Solanum lycopersicum* L.; abiotic stress; drought; photosynthesis; yield; fruit weight; color; firmness

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1. Introduction

Tomato (*Solanum lycopersicum* L.) is one of the most widespread and consumed vegetables worldwide. Regardless of the fact that they are grown in different climatic regions (continental, tropical, and subtropical), they are sensitive to unfavorable environmental conditions [1–3]. Among the abiotic stresses, drought causes many adverse effects on plant growth and development, which ultimately lead to yield loss. The reduction in productivity is due not only to flower and flower bud abscission and a decrease in fruit number and size [4–6] but also an interruption in the photosynthesis process during the water deficit period [7]. Depending on the genotype, developmental stage, and duration of exposure and intensity of the water stress, the yield loss can reach 40–60% [8–11].

Narrow genetic variation within crops and the complex and multigenic nature of drought tolerance traits make it difficult to identify the sources of drought tolerance [12]. The transfer of drought resistance genes from wild species is possible and has been reported in tomato, but it poses several problems such as cross incompatibility, hybrid viability, hybrid sterility, and linkage of several undesirable genes with desirable ones [13]. The use of local germplasm as a source of drought-tolerant genotypes is one of the promising ways to further exploit this gene pool in tomato breeding programs [14–16]. Landraces are very heterogeneous and are often grown in areas with unfavorable conditions with minimal yield loss [17–19]. Presumably, as a result of natural selection, they have developed specific traits that allow them to adapt better to environmental limitations [20,21].

Considering that drought stress affects different aspects of plant growth and physiology, the evaluation of the stress response should include both morphological and physiological measurements [21–23]. Various indexes are taken into account in the assessment of drought resistance to characterize tomatoes' physiological and genetic basis, such as the fruit set, fruit weight, fruit size, shoot and root morphology, water use efficiency (WUE), and other physiological parameters [8,21].

There are several ways to study large-scale patterns of the distribution and variety of landraces, describing their behavior in stressful and normal environments, and screening drought-tolerant landraces [24]. The photosynthetic apparatus (PSA) and especially the photosystem II (PS II) belong to the systems of plants sensitive to stress factors. In this respect, chlorophyll fluorescence measurement as a non-destructive, simple, rapid, and highly sensitive method can be successfully applied in stress response studies [21,25]. The analysis of changes in the parameters of chlorophyll fluorescence is considered a suitable criterion for studying the influence of various stress factors on the functional state of the photosynthetic apparatus [23,26,27]. The relative maximal variable fluorescence (Fm/Fo), maximum quantum efficiency of PSII (Fv/Fm), quantum yield of electron transport (ΦP0), electron transport flux per reaction center (RC) (ET0/RC), and vegetative growth parameters are used to detect the impact of drought stress on tomato plants [21].

In recent years, it has become increasingly clear that the development of tomato cultivars with enhanced drought stress tolerance is highly desirable and is one of the most sustainable approaches to achieving food security. In this regard, efforts are being made to understand the mechanisms of plant drought tolerance, the discovery of genes involved in the stress response, and the interaction of genetic and environmental factors [28,29]. Using molecular markers, local tomato landraces with higher drought tolerance have been identified and used in the breeding process as genetic resources for crop improvement due to their naturally enhanced tolerance to abiotic stress [14,30,31].

The current study aimed to assess local tomato landraces in terms of their drought tolerance using an integrated approach, including morphological traits and physiological parameters. Our hypothesis is that local tomato germplasm represents an unexploited source for drought resistance, and accessions tolerant to water deficit will be identified.

2. Materials and Methods

2.1. Plant Material and Growth Conditions

Five tomato landraces from the collection of the Maritsa Vegetable Crops Research Institute (MVCRI) were studied (Table 1). The landraces used in this study represent the diversity in terms of fruit shape, color, and fruit quality in a larger collection. They were selected based on their yield stability under diverse growing conditions (non-published data). The drought-sensitive variety MoneyMaker (MM) and the drought-tolerant JAG 8810 F1 (JAG) (Seminis Vegetable Seeds, Inc., Oxnard, CA, USA) were used as controls. The seeds of the selected accessions were sown at the beginning of April in an unheated greenhouse. The tomato seedlings were transplanted at the beginning of May at the stage of 2nd–3rd true leaf into the field using the method of mid-season production of indeterminate tomatoes [32]. Soil moisture at 15 and 30 cm depth (kPa) was monitored on a daily basis using the weather station Caipos Wave (Caipos GmbH, Seiersberg, Austria) and used to determine the time for watering. Based on sensor measurements, the optimal irrigation rate (100%) in the 30 cm layer was calculated according to the following formula: $IR = [10 \times 0.3 \times BD \times (FC - \delta)] \times K$. Here, IR is the irrigation rate (in mm); BD—the bulk density of the soil (1.5 g cm^{-3}); FC—field capacity relative to the absolute dry weight of the soil (22.0%); δ—the pre-irrigation soil moisture relative to the absolute dry weight of the soil (in %); K—the coefficient of reduction in the irrigation rate, taking into account the area occupied by plants (K = 0,66, i.e., 66% of the area is irrigated). Two watering regimes—100% (optimum) and 50% reduced—were applied. The reduced irrigation accounted for 50% of the amount of water given to the control plants. It was applied 20 days after transplanting the seedlings and continued during the whole vegetation period from June to August. The experiment was carried out at MVCRI field (42°10′30.8″ N 24°45′43.3″ E) in a randomized complete block design with two replications for each of the irrigation regimes. Each replication was composed of seven accessions, and each accession was presented by 10 plants. A microflow drip irrigation system with a capacity of 2 L h^{-1} was used.

Table 1. Characteristics of tomato landraces.

Code	**1209**	**1352**	**1356**	**1370**	**1422**	**MoneyMaker**	**JAG8810**
Picture							
Shape	Slightly flattened	Rounded	Heart-shaped	Flattened	High rounded	Rounded	Rectangular
Size	Very large	Large	Large	Very large	Medium	Medium	Medium
Color	Pink	Red	Orange	Yellow	Brown	Red	Red

2.2. Yield and Yield-Related Traits

Flower number (FlN) and fruit number (FrN) were measured as a sum of all flowers and fruits from the 1st to 6th trusses. The fruit set (FS) was calculated as follows: FS = (FrN/FlN) × 100. Fruit weight was estimated as an average value of 10 fruits per replication from 2nd to 5th trusses. Total yield (g plant^{-1}) was calculated as a sum of the weight of all fruits from the 1st to 6th trusses. All these traits were evaluated in two replications, with three plants per replication.

2.3. Color Indexes and Firmness

For analyses of color and firmness, fruits were harvested at the full maturity stage from 2nd to 5th trusses. Measurements were conducted at the midpoint of the fruit length at two opposite points per fruit, with one fruit per tress, and three plants per replication. Fruit firmness was measured using a durometer (53,215 Fruit Hardness Tester, TR Turoni srl, Forli, Italy). Fruit color (skin color) was determined using a Minolta colorimeter (Model CR-400; Minolta Co. Ltd., Osaka, Japan) using the Commission Internationale de l′Eclairage (CIE) for color measurements and color space. Values were recorded as L* (lightness), a* (coloration intensity of −greenness to +redness), and b* (coloration intensity of −blueness to +yellowness). The different color indexes were calculated according to the following equations: chroma (C): $(a^{*2} + b^{*2})^{0.5}$; hue: $\tan^{-1}(b^*/a^*)^2$; color index (CI): $2000a^*/L^*(a^{*2} + b^{*2})^{0.5}$.

2.4. Chlorophyll a (Chl a) Fluorescence Measurements

Chlorophyll fluorescence was measured using a PEA portable fluorometer (Plant Efficiency Analyzer MK2, Hansatech Instruments King's Lynn, Norfolk, UK). The following parameters characterizing the changes in photosystem II were collected: Fo—initial/minimal fluorescence, Fm—maximum fluorescence, and Fv—variable fluorescence (Fv = Fm − Fo) in dark-adapted leaves. They were used to calculate the ratios Fv/Fm, which represent the maximum quantum yield of PSII, and Fv/Fo, which estimates the maximum primary yield of photochemistry in PSII. Chlorophyll fluorescence measurement was performed during the fruit set of the third cluster on one fully expanded leaf per landrace and per water treatment on day 0 (the day after irrigation) and twice more at 7 days' interval (at day 7 and day 14) before the next irrigation.

The fluorescence measurement was performed using a saturating light of 3000 µmol m^{-2} s^{-1}. Intact, dark-adapted for 30 min, well-developed leaves (fourth–fifth leaf below the growth tip) were measured. The parameters of the induction curves of the fluorescence emission were recorded in the afternoon hours of the day when the temperature was above 34–38 °C. The parameters taken at the beginning of the measurement in the morning at a temperature of 23–27 °C and optimum irrigation were used as initial controls. Fluorescence parameters were recorded in two replicates, two plants per replicate, and three measurements per plant, three times during the applied stress (0, 7, and 14 days) as described above.

2.5. Statistical Data

The experimental results were statistically processed by Tukey's HSD Test and Two-way analysis to compare differences among accessions grown in two watering regimes (SPSS 16.0 software). The percentage of changes (Ch%) of the studied traits from optimum to reduced irrigation was calculated as follows: Ch% = (TRI/TOI) × 100 − 100. Here, TRI is the value of the trait in reduced irrigation, and TOI is in optimum irrigation.

3. Results

3.1. Yield and Fruit Set

The flowering and fruit set stages are the most sensitive to water stress and have a direct effect on yield loss. Tukey's HSD Test showed significant differences in the fruit set between the tested accessions and controls in the reduced irrigation regime and varied from 27.2% to 69.2% (Table 2). Under optimum irrigation, the fruit set ranged from 61.7% to 79.2% with no statistically significant differences between accessions and controls. Similar values of the fruit set between the two watering regimes were observed in accessions 1352, 1422, and tolerant control JAG 8810. Under reduced irrigation, two accessions showed a similar response to the tolerant control, but only one, 1422, was significantly better than the sensitive control, MoneyMaker.

Table 2. Tukey's HSD Test on fruit set between five landraces and controls.

Irrigation Regime	**Reduced**		**Optimum**		**Ch%**
Landrace	**Mean**	**±SD**	**Mean**	**±SD**	
1209	27.2 ^{c}	±19.09	61.7 ^{ns}	±16.67	−55.84
1352	58.3 ^{ab}	±9.62	64.3 ^{ns}	±14.05	−9.26
1356	38.6 ^{c}	±2.10	65.6 ^{ns}	±17.63	−41.76
1370	37.5 ^{c}	±18.46	69.5 ^{ns}	±18.89	−46.04
1422	69.2 ^{a}	±15.32	79.2 ^{ns}	±14.13	−12.63
Controls					
MoneyMaker	46.6 ^{bc}	±4.69	76.6 ^{ns}	±6.44	−47.23
JAG8810	65.0 ^{a}	±5.85	73.5 ^{ns}	±13.96	−6.58

Values in the same column with different superscripts differ significantly ($p < 0.05$) according to Tukey's HSD Test.

A high impact of drought was found in the yield and yield-related traits (Table 3, Figure 1). The yield reduction under reduced irrigation was observed in five out of the seven tested genotypes. The highest yield reduction, by 73.6%, was recorded in genotype 1209, compared to the yield obtained under optimal irrigation conditions. The trend regarding the number of fruits per plant and average fruit weight was similar. Depending on the accession, the reduction was in the range from 5.9% (1352) to 45.5% (1370) and from 9.5% (1370) to 59.4% (1209), respectively, compared to the well-watered plants. Under water deficit, accession 1352 showed a slight decrease in yield, fruit number, and weight with similar values as the tolerant control. The other four landraces had values of the investigated traits near those of the sensitive control.

Table 3. Impact of water deficit on productivity, fruit number, and average fruit weight in five tomato landraces and two controls (sensitive MM and tolerant JAG).

Genotype	Yield (g·Plant^{-1})				Fruit Number				Average Fruit Weight (g)			
	Reduced		Optimum		Reduced		Optimum		Reduced		Optimum	
	Mean	±SD	Mean	±SD	Mean	±SD	Mean	±SD	Mean	±SD	Mean	±SD
1209	702 ^{d}	±80.6	2662 ^{ab}	±45.3	5 ^{c}	±0.7	9 ^{b}	±0.7	127.8 ^{b}	±1.8	314.5 ^{a}	±31.4
1352	2263 ^{a}	±78.5	2427 $^{a\text{–}c}$	±328.1	8 ^{c}	±2.8	9 ^{b}	±0.7	299.8 ^{a}	±96.2	284.9 ^{ab}	±14.9
1356	1084 ^{cd}	±241.8	2659 ^{ab}	±41.7	10 ^{c}	±1.4	13 ^{b}	±2.8	107.8 ^{b}	±8.9	209.1 ^{c}	±42.3
1370	1380 ^{bc}	±454.7	2746 ^{a}	±89.8	6 ^{c}	±1.4	11 ^{b}	±1.4	227.3 ^{a}	±22.2	251.2 ^{bc}	±24.1
1422	723 ^{d}	±113.8	1842 ^{c}	±56.6	22 ^{b}	±0.0	28 ^{a}	±0.0	32.8 ^{b}	±5.2	65.8 ^{d}	±2.0
Controls												
MM	1334 ^{bc}	±127.3	1999 ^{c}	±540.9	33 ^{a}	±4.6	31 ^{a}	±4.6	41.8 ^{b}	±10.3	64.9 ^{d}	±7.2
JAG	1742 ^{ab}	±202.2	2047 ^{bc}	±249.6	27 ^{b}	±2.1	26 ^{a}	±0.0	65.6 ^{b}	±2.4	78.7 ^{d}	±9.6

Each observation is a mean, ±SD. Values in the same column with different superscripts differ significantly ($p < 0.05$) according to Tukey's HSD Test.

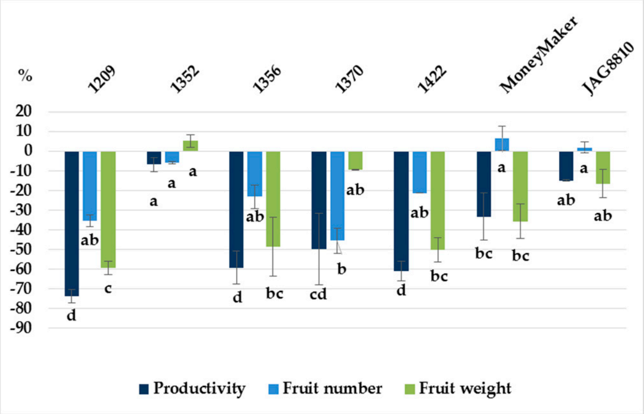

Figure 1. Percentage of change in the value of productivity, fruit number, and fruit weight in five tomato landraces and two controls under 50% reduced irrigation compared to the optimum irrigated plants. Each observation is a mean, ±SD. The different letters under the bars of the same color indicate statistically significant differences according to Tukey's HSD Test ($p < 0.05$).

3.2. Fruit Color and Firmness

In general, the data indicated that the watering regime did not significantly alter the fruit color based on the CIELab parameters and calculated color indexes (chroma and hue). Only L* and b* were higher in accessions 1352, 1370, and 1422 under reduced irrigation conditions compared to the optimum ones (Figure 2). The results of the ANOVA showed that the genotype was significant in all traits, while the irrigation condition caused significant results in three traits (L*, a*, and firmness) (Table 4).

Table 4. Two-way analyses of variance for fruit physical and physiological parameters. L*: lightness, a*: redness, and b*: yellowness; C*: chroma and CI*: color index.

	L*	a*	b*	C*	CI*	Hue	Firmness	Fo	Fv/Fm	Fv/Fo
Genotype (G)	***	***	***	***	***	***	***	***	***	***
Irrigation regime (I)	*	*	ns	ns	ns	ns	***	***	***	***
G × I	**	**	ns	*	ns	ns	***	*	ns	ns

* $p \leq 0.05$; ** $p \leq 0.01$; *** $p \leq 0.001$.

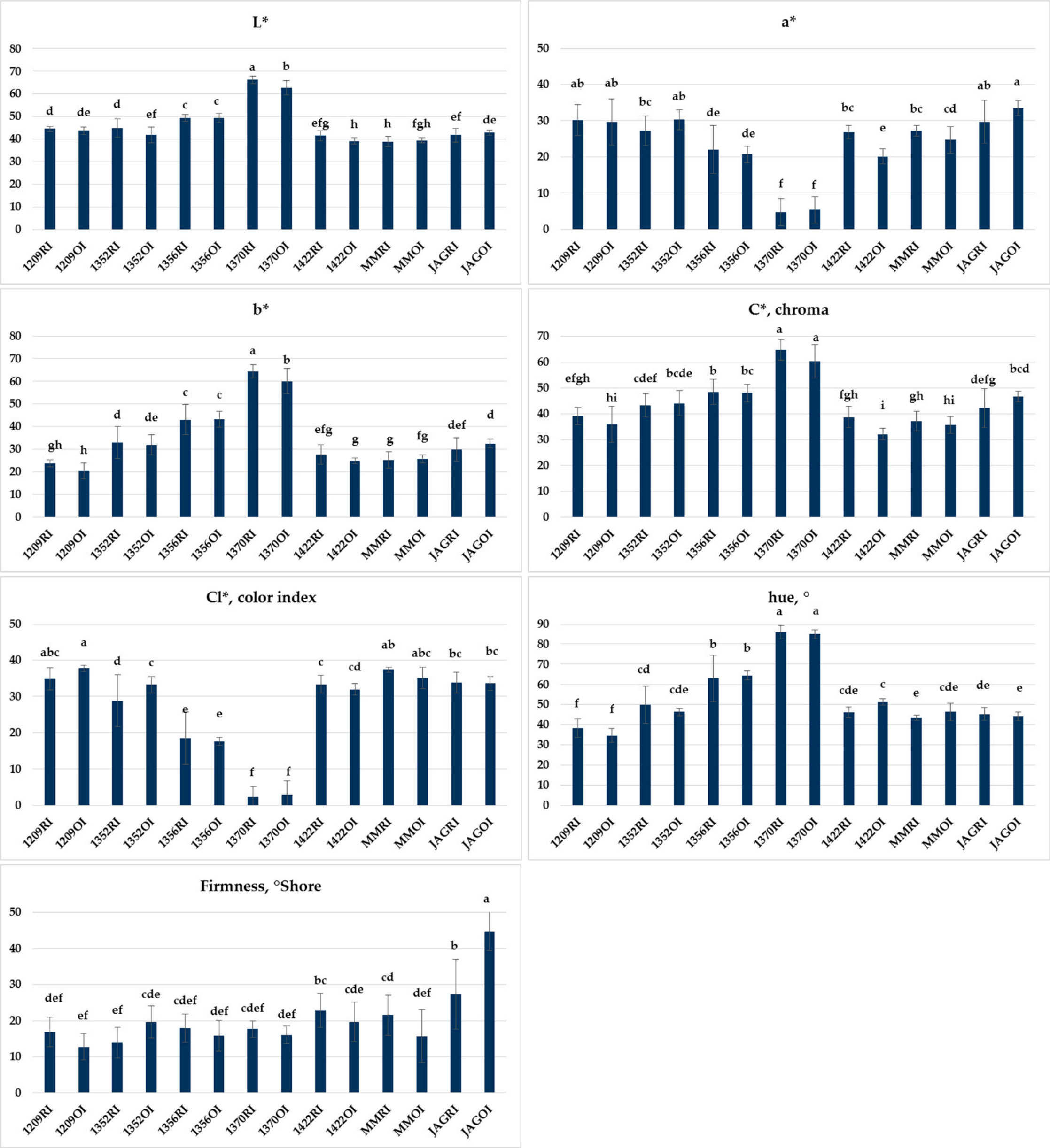

Figure 2. Effect of water regime (optimum irrigation, OI; reduced irrigation, RI) for fruit physical traits of five landraces and two controls (sensitive MM and tolerant JAG). L*: lightness, a*: redness, and b*: yellowness; C*: chroma, CI*: color index. Each observation is a mean, ±SD. For each figure, the different letters above the bars indicate statistically significant differences according to Tukey's HSD Test ($p < 0.05$).

3.3. Chlorophyll Fluorescence

The experimental data showed that drought stress had different effects on the chlorophyll fluorescence parameters depending on how long the stress lasted. The obtained results demonstrate a well-defined negative effect of the applied drought in combination with high temperatures on the photosynthetic activity of all the studied genotypes. Significant differences are observed between the landraces.

After exposure to drought stress for seven and fourteen days, Fo showed significant differences between the irrigation regimes and landraces used ($p \leq 0.001$), as well as in their interaction ($p \leq 0.05$). Fv/Fm and Fv/Fo were significantly different among the irrigation regimes and landraces, but the interaction between the factors was insignificant (Table 4).

The data on the main parameters of chlorophyll fluorescence under the two regimes of soil moisture are shown in Table 5. These indicators were recorded during the reproductive period of tomato development at different values of the temperature factor. The data show that in the morning readings characterized by optimal temperature for tomatoes, the plants of all genotypes demonstrated a very good physiological condition. In this measurement, drought has not yet occurred, which explains why both the control (optimum irrigation) and drought-stressed plants have high values of chlorophyll fluorescence parameters. The chlorophyll fluorescence values were recorded under mild drought and high temperature on the 7th day of the drought stress (afternoon measurements). A trend in the changes in the studied parameters is obvious, the degree of which varies with the individual genotypes. Similar changes were also observed on day 14 of the applied drought stress (afternoon measurements) (Figure 3).

Table 5. Variation in chlorophyll fluorescence parameters (Fo, Fv/Fm, and Fv/Fo) of the leaves of tomato plants cultivated under optimum (OI) and reduced irrigation (RI).

Day	**0**		**7**		**14**		**0**		**7**		**14**	
	Mean	**±SD**	**Mean**	**±SD**	**Mean**	**±SD**	**Mean**	**±SD**	**Mean**	**±SD**	**Mean**	**±SD**
	1209 RI						1209 OI					
Fo	417 ^{c}	±16.6	483 ^{a}	±16.9	487 ^{a}	±24.7	445 ^{b}	±7.1	421 ^{bc}	±7.2	404 ^{c}	±16.6
Fv/Fm	0.84 ^{a}	±0.01	0.77 ^{c}	±0.01	0.75 ^{d}	±0.01	0.81 ^{b}	±0.01	0.84 ^{a}	±0.01	0.84 ^{fa}	±0.01
Fv/Fo	5.4 ^{a}	±0.14	3.4 ^{c}	±0.25	3.0 ^{d}	±0.11	4.2 ^{b}	±0.10	5.4 ^{a}	±0.17	5.4 ^{a}	±0.25
	1352 RI						1352 OI					
Fo	425 ^{b}	±23.8	502 ^{a}	±41.5	442 ^{b}	±16.2	445 ^{b}	±29.3	414 ^{b}	±21.4	367 ^{c}	±20.9
Fv/Fm	0.82 ^{a}	±0.01	0.77 ^{b}	±0.02	0.77 ^{b}	±0.01	0.81 ^{a}	±0.02	0.82 ^{a}	±0.01	0.83 ^{a}	±0.01
Fv/Fo	4.5 ^{ab}	±0.30	3.3 ^{c}	±0.36	3.4 ^{c}	±0.16	4.4 ^{b}	±0.49	4.7 ^{ab}	±0.36	4.9 ^{a}	±0.32
	1356 RI						1356 OI					
Fo	392 ^{de}	±11.7	454 ^{a}	±11.9	443 ^{ab}	±24.9	403 ^{cd}	±7.0	423 ^{bc}	±17.6	372 ^{e}	±10.1
Fv/Fm	0.84 ^{a}	±0.01	0.79 ^{b}	±0.01	0.79 ^{b}	±0.02	0.84 ^{a}	±0.00	0.84 ^{a}	±0.01	0.85 ^{a}	±0.01
Fv/Fo	5.5 ^{ab}	±0.10	3.7 ^{ef}	±0.11	3.7 ^{fg}	±0.44	5.2 ^{ab}	±0.10	5.1 ^{b}	±0.24	5.5 ^{a}	±0.13
	1370 RI						1370 OI					
Fo	418 ^{a}	±15.0	443 ^{a}	±33.2	409 ^{a}	±11.8	434 ^{a}	±27.1	429 ^{a}	±21.8	376 ^{b}	±2.1
Fv/Fm	0.84 ^{ab}	±0.00	0.78 ^{e}	±0.03	0.79 ^{de}	±0.01	0.81 ^{cd}	±0.01	0.82 ^{bc}	±0.02	0.85 ^{a}	±0.01
Fv/Fo	5.3 ^{a}	±0.16	3.7 ^{d}	±0.53	3.8 ^{cd}	±0.18	4.4 ^{bc}	±0.38	4.8 ^{b}	±0.52	5.7 ^{a}	0.06
	1422 RI						1422 OI					
Fo	409 ^{b}	±11.1	531 ^{a}	±68.9	528 ^{a}	±16.3	411 ^{b}	±5.6	389 ^{b}	±33.0	399 ^{b}	±14.5
Fv/Fm	0.84 ^{a}	±0.01	0.75 ^{c}	±0.03	0.78 ^{b}	±0.01	0.82 ^{a}	±0.01	0.84 ^{a}	±0.02	0.85 ^{a}	±0.01
Fv/Fo	5.4 ^{a}	±0.37	3.1 ^{c}	±0.51	3.5 ^{c}	±0.14	4.7 ^{b}	±0.08	5.4 ^{a}	±0.68	5.6 ^{a}	±0.23
	MoneyMaker RI						MoneyMaker OI					
Fo	424 ^{b}	±14.6	531 ^{a}	±53.5	548 ^{a}	±42.5	447 ^{b}	±5.6	373 ^{c}	±5.8	399 ^{bc}	±20.2
Fv/Fm	0.82 ^{a}	±0.01	0.73 ^{c}	±0.03	0.74 ^{c}	±0.02	0.79 ^{b}	±0.01	0.82 ^{a}	±0.01	0.83 ^{a}	±0.01
Fv/Fo	4.7 ^{a}	±0.42	2.8 ^{c}	±0.38	2.9 ^{c}	±0.34	3.7 ^{b}	±0.06	4.7 ^{a}	±0.18	5.0 ^{a}	±0.24
	JAG8810 RI						JAG8810 OI					
Fo	391 ^{bc}	±5.5	419 ^{a}	±9.0	409 ^{ab}	±21.7	385 ^{bc}	±19.6	383 ^{c}	±4.2	370 ^{c}	±26.5
Fv/Fm	0.85 ^{a}	±0.01	0.81 ^{b}	±0.01	0.80 ^{b}	±0.01	0.84 ^{a}	±0.01	0.84 ^{a}	±0.01	0.85 ^{a}	±0.01
Fv/Fo	5.6 ^{a}	±0.22	4.3 ^{c}	±0.12	4.1 ^{c}	±0.22	5.4 ^{ab}	±0.24	5.1 ^{b}	±0.24	5.6 ^{a}	±0.37

Each observation is a mean, ±SD. Values in the same column with different superscripts differ significantly ($p < 0.05$) according to Tukey's HSD Test.

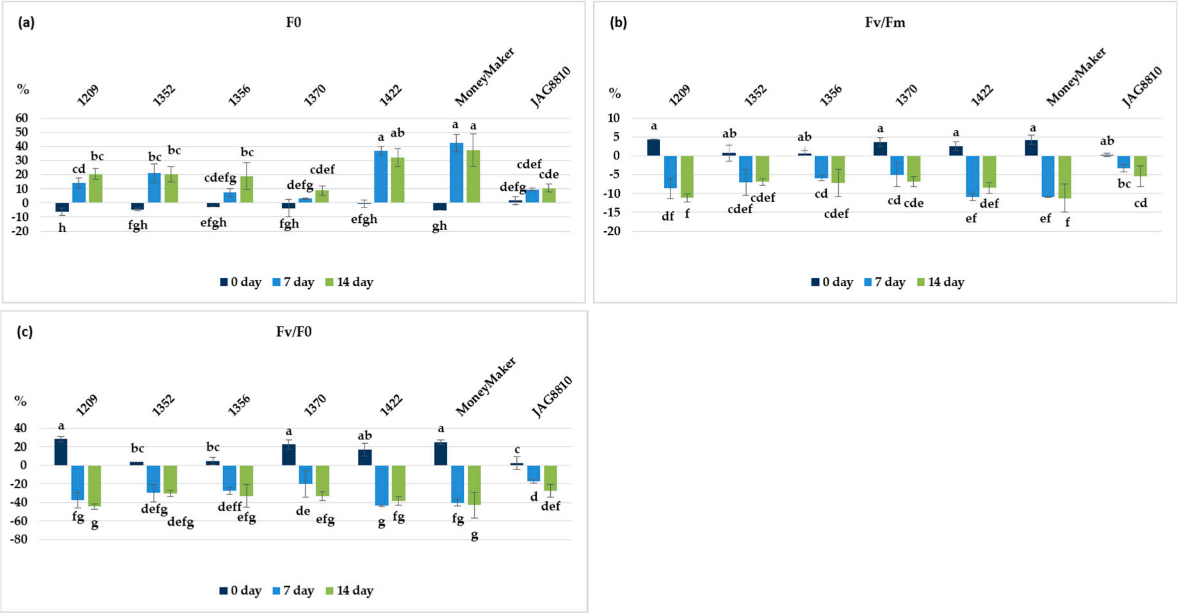

Figure 3. Effects of different water deficits on (**a**) initial fluorescence (Fo), (**b**) maximum quantum efficiency of PSII photochemistry (Fv/Fm), and (**c**) Fv/Fo in leaves of tomato *S. lycopersicum* after 7 and 14 days of water deficit. Means, SE (n = 5). The different letters near the bars of the same color indicate statistically significant differences according to Tukey's HSD Test ($p < 0.05$).

The experimental data showed that in most of the studied landraces, the ratio Fv/Fm was slightly reduced. The average Fv/Fm ratio in all seven genotypes under control conditions was 0.833 on the 7th and 0.834 on the 14th day of the treatment. During drought stress, the average Fv/Fm ratio was 0.771 after the first 7 days and 0.774 after the 14 days, which reduced by 7.4% and 8.2%, respectively. The largest drop in the maximum quantum efficiency of the PSII (Fv/Fm) value in dark-adapted leaves was recorded for landrace 1422 (0.750) and the drought-sensitive control MoneyMaker (0.735) on the 7th day, and for 1209 (0.749) and MoneyMaker (0.741) on the 14th day (Table 5). The drought most significantly reduced the Fv/Fm ratio by 9–11% (7–14 days) in landrace 1209, similarly to the drought-sensitive control MoneyMaker (11%).

The measured initial fluorescence (Fo) values in the drought-stressed plants increased compared to the well-watered plants of the same genotypes. After 7 and 14 days of treatment, the Fo values increased on average by 17.5% and 21.5%, respectively. Among the studied landraces, 1370 showed changes in Fo values near those of the tolerant control JAG, while in 1422, the increase in the Fo values was higher and near to that for the sensitive control, MoneyMaker (Table 5, Figure 3a). The maximum primary yield of photochemistry in PSII (Fv/Fo) decreased under drought stress in all the accessions compared to the control plants (optimal irrigation) (Table 5). As a result of the stress exposure, a significant decrease in the parameter Fv/Fo was observed on day 7 in line 1422 (43.4%) and on day 14 in line 1209 (44.4%) (Figure 3c). The percentage change in the parameter Fv/Fo was the lowest in landraces 1370 and 1352, with the reduction ranging from 23.0% (day 7) to 30.4% (day 14).

Based on the values of the chlorophyll fluorescence parameters, particularly well highlighted by their percentage relationships (Table 5, Figure 3), landraces 1209 and 1422 can be assigned to the drought-sensitive group. Genotypes 1352, 1356, and 1370 can be classified as moderately sensitive to the applied drought, of which line 1352 is the least affected.

4. Discussion

Tomato (*Solanum lycopersicum* L.) is among the most cultivated and consumed vegetables on a global scale. However, the results of many investigations indicate that tomato plants are sensitive to water stress, not only during the vegetative growth phase but especially during the stages of flowering and the fruit set [33]. Landraces, as part of the genetic diversity in tomatoes, and in addition to the unique taste preferred by consumers, are increasingly included in breeding programs due to their potential to adapt to stressful environments. As a result, studies focusing on the characterization of the drought tolerance of local germplasm are being conducted [17,18,34–36]. The fruit set is among the most important traits that have a direct impact on yield. In conditions of water deficit, the reduction in yield was due to the dropping of flowers before fruit formation as well as to the formation of a smaller number of flowers [6,37]. That is why the analysis of the flower and fruit development under drought stress indicated the reproductive and productive performance of the plants. In the current study, the fruit set varied from 27.2% to 69.2% under reduced irrigation and from 61.7% to 79.2% under optimum irrigation. The largest differences in the fruit set between the two irrigation regimes were observed in accession 1209, exceeding 55%, while in accessions 1352 and 1422, the loss of flowers was less than 12%. Similar results have been obtained in other studies [38,39]. According to some authors, the higher rate of flower abscission is probably due to a reduction in photosynthesis during stress and a decrease in assimilated supply to the developing floral organs, abnormal carbohydrate metabolism in floral development, or changes in the level of hormones such as ABC, IAA, and the peptide hormone phytosulfokine, controlling flower drop in tomato [4,5,40].

At the same time, water deficit resulted in reductions in the fruit weight and fruit number [41–43]. Changes in metabolic and hormonal pathways associated with distinct fruit tissues are one of the reasons for decreases in fruit size and weight [44]. During a water deficit, the water content of the fruit decreases, which causes a reduction in fruit enlargement and also a reduction in fruit weight [45]. The results of the present study showed that drought stress negatively affects fruit weight to a greater extent than fruit number. Among the landraces, 1209 had the highest reduction in fruit weight, while 1352 showed no significant changes in fruit weight under both irrigation regimes. Considering that large-fruited accessions were studied, a significant decrease in fruit weight was the main reason for the observed yield loss. These data confirmed our previous experiment when the decrease in fruit weight was higher in the big-fruited accessions [46]. The decrease in fruit weight and number can be used as an indirect indicator of drought resistance/susceptibility [14].

The fruit size, color, and shape, which characterize appearance, have a direct effect on consumer preferences [47]. Data in the literature have indicated that fruit firmness and color index are positively affected by drought stress [48,49]. In the present study, there are no significant differences in fruit firmness, color measured by CIELab parameters, or calculated color indexes (chroma and hue). Nevertheless, the values of the color parameters and fruit firmness were higher under the conditions of reduced irrigation, resulting in higher L* (lightness) and b* (yellowness) values due to physiological and biochemical responses to water stress. The improved color of tomatoes subjected to water stress is due to the increased content of lycopene and carotenoids as a result of the increased ethylene content in the fruit [50,51]. Also, drought often leads to a decline in chlorophyll synthesis or an increase in chlorophyll degradation [52,53]. As chlorophyll decreases, the green pigmentation fades, leading to lighter-colored fruits with higher L* values. The induced oxidative stress due to water deficit may alter the metabolic pathways of pigments and lead to the relative dominance of lighter pigments such as beta-carotene (yellow-orange pigment) more than lycopene (red pigment), shifting the color balance towards a more yellowish hue or increased b* value [54,55]. In addition, drought stress can accelerate ripening, which makes the fruit appear lighter and more yellow, as the natural color development shifts. These changes reflect the plant's adaptive strategies to cope with water stress and may impact the fruit's visual and nutritional quality [53]. On the other hand, drought increased the firmness of tomatoes, probably due to an increase in the total soluble solids content and cellular density and a reduction in the fruit size [51,56].

Long-term drought can impair photosynthesis by weakening the photosynthetic system and changing photosynthetic pigments [52,57]. Measuring the chlorophyll fluorescence is a highly sensitive method for identifying changes in photosynthetic activity that has been widely used to study both biotic and abiotic stress in plant species [24].

Changes in the parameter Fv/Fm, which represents the maximum potential quantum efficiency of PSII, are the most common way to identify damage in tested plant genotypes [21,26,58]. It has been determined that the most appropriate critical photochemical parameter for assessing the photosynthetic process is measuring the maximal photochemical quantum yield of PSII.

There is evidence that the initial fluorescence (Fo) rises in response to temperature stress [59]. This parameter is frequently linked to drought stress in the field. After 7 (or 14) days of drought in our measurements, we saw an increase in this indicator in the stressed plants as compared to the control. Measuring changes in the Fv/Fm ratio is the most common approach for detecting damage [21,58]. The maximum quantum yield (Fv/Fm), an essential photochemical quenching parameter for determining the maximum quantum efficiency of PSII, demonstrated no significant changes until the experiment's conclusion. In normal, non-stressed conditions, the Fv/Fm ratio is close to 0.83 for the majority of plant species. When plants are stressed, Fv/Fm decreases, depending on the plant cultivar and growth status [60]. In the current study, the chlorophyll fluorescence parameter Fv/Fm in the tomatoes decreased slightly under drought at 7 and 14 days from the onset of drought treatment. Lower values of this parameter indicate that plants grown under stressful conditions sustain injury to the PSII reaction centers, which reduces the electron transport productivity [61]. Our results support this approach [60,62], since the Fv/Fm ratio demonstrates the obtained differences between the measured landraces under drought conditions, but the variable Fv/Fo also provides information on the level of damage to a greater extent. The ratio Fv/Fo, which measures the state and efficiency of the electron transport chain during photosynthesis, is an effective indicator of how drought stress affects a plant's photosynthetic machinery. A drop in this fluorescence parameter indicates a disruption in electron transmission during photosynthesis.

Fv/Fo, similarly to Fv/Fm, significantly decreased in all the tested landraces, especially in the more sensitive ones, on both measurement dates during the applied drought. The ratio Fv/Fo, which characterizes the efficiency of electron transport in photosynthetic processes, is significantly more sensitive to various stress factors than Fv/Fm and shows a pronounced tendency to negatively influence under different irrigation treatments. The lower values of this ratio are an indication of a reduced efficiency of electron transport in all the studied genotypes.

Drought tolerance is difficult to assess based on a single trait, as it involves a combination of physiological, morphological, and molecular changes. However, the results of the present study suggest that the fruit set and Fv/Fm ratio could serve as reliable indicators of the plant stress response. The fruit set is a crucial trait, as it reflects the drought tolerance of the reproductive organs, particularly the male organs of the flower, which are highly sensitive to stress [5,63]. A decrease in the Fv/Fm ratio under drought stress indicates damage to the photosystem and a reduction in the photosynthetic efficiency [62,64].

It is known that drought tolerance depends on the interaction of several mechanisms operating at different levels—morphological, physiological, and molecular, comprehensively reviewed by Conti et al. [30]. It was observed that a lower stomatal conductance is connected with lower water consumption and higher water use efficiency [35,65]. Several candidate genes associated with drought tolerance also have been identified [29,66].

Drought-tolerant landraces can be particularly beneficial for regions facing water scarcity, ensuring stable yield, while supporting sustainable farming practices. They could also be integrated into breeding programs to enhance drought resilience in elite tomato varieties, thus providing a natural solution for adapting agricultural systems to climate changes. In addition, the modification of the tomato genome through both transgenic approaches and genome editing techniques is increasingly being applied to study and enhance drought stress tolerance at the molecular level [29,67]. Since drought is often accompanied by other environmental stresses such as heat, salinity, or poor soil conditions, the study of multiple abiotic stress tolerance is a key future direction for research.

5. Conclusions

The tested landraces exhibited different responses to applied water stress. The assessment based on changes in the studied morphological and physiological traits showed that the landraces 1352, 1356, and 1370 have a higher tolerance to drought while 1209 and 1422 were sensitive. Moreover, the most sensitive morphological character with a direct effect on the yield was the average fruit weight. Changes in the chlorophyll fluorescence parameters were found to depend not only on the genotype but also on the duration of stress exposure.

Landrace 1352, characterized by indeterminate growth habit and large, rounded, and red-colored fruits, showed a significantly lower reduction in yield and physiological parameters under reduced irrigation. It could serve as a potential parent in future breeding programs to develop new tomato varieties combining drought tolerance with quality.

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